SSERVI-ESF14-215

Author: JAMES BAUER

ORAL

Volatiles

NEOWISE Observations of Comets : CO/CO2 Gas Emission

NEOWISE is the planetary-funded mission that utilizes data from the Wide-Field Infrared Survey Explorer (WISE) spacecraft to detect and characterize moving objects. NEOWISE has provided a large statistical sampling of comets in various states of activity, containing a variety of types of comets. This data set provides a unique opportunity to discern the trends in their observable properties and compare the mean properties between classification schemes, and may provide a basis for understanding the differences between the underlying populations of comet subtypes. The WISE spacecraft discovered 22 new cometary bodies and observed over 160 comets during the prime mission (January 2010 through January 2011), yielding the largest sample of comets yet observed at thermal-IR wavelengths. This collection, obtained before the depletion of the cryogen at the end of September 2010, offers a diverse range of comet behavior including highly active and inactive bodies from both long period comet (LPC, orbital period > 200 years) and short period comet (SPC, period < 200 years) populations. In particular, our analysis characterizes the production rates and extent of the CO/CO2 gas species, basic volatiles of likely primordial origin that are most easily detected at these wavelengths. These primitive volatile species, which sublimate at faster rates than H2O when the comet is at larger distances from the Sun, may indicate the degree of processing a particular comet has undergone and how depleted their surfaces are of volatiles in general, including water. Comparison of the 4.6 micron band signal, containing significant signal from emission lines of these two gas species at 4.26 (CO2) and 4.67 (CO) microns, with the signal in the other 3 bands at 3.4, 12, and 22 microns, facilitates separation of the gas from the nucleus and dust flux contributions. In the comets discovered by WISE, about 1/3rd showed significant 4.6 micron band flux excess, including 2 that are NEOs, and one that approaches within 4 lunar distances from the Earth's orbit. In December of 2013, the WISE spacecraft was re-activated to continue its search for NEOs under the NEOWISE program. As the NEOWISE mission continues to take images, the number of active comets observed by WISE grows. As of April 2014, nearly a dozen comets have been observed in the restart of NEOWISE, including the newly discovered Halley-Family comet C/2014 C3 (NEOWISE). Though these images are only in the 3.4 and 4.6 micron bands, NEOWISE has been able to provide constraints on gas production for several of these comets. We will discuss how the results of the prime mission cometary data are being utilized to extract more accurate CO/CO2 production rates from the 2-band NEOWISE data, and what the sample of 160 comets from the prime mission indicates regarding cometary composition in the LPC and SPC cometary populations.This work was supported by NEOWISE, which is a project of the Jet Propulsion Laboratory/California Institute of Technology, funded by the Planetary Science Division of NASA.

Author: SANDRA BLEVINS
POSTER

Volatiles

Snow line localization in classical protoplanetary disks

Protoplanetary disks are volatile-rich environments capable of producing the essential conditions that make planet formation viable. Establishing a molecular inventory of dominant volatile species in the planet-forming zones surrounding young, solar-type stars elevates our understanding of the chemistry involved with planet formation, composition and disk evolution. Specifically we wish to compare these young systems to the solar nebula so that we may better understand the initial conditions driving planet formation and explore the uniqueness of our solar system and its distribution of water. For this study we measure the water vapor content and determine the location of the condensation front, or snow line, for four classical disks selected for the strong water emission present in their mid-infrared spectra. To accomplish this we combine deep Herschel PACS observations with high resolution Spitzer IRS spectra to create molecular maps comprised of water lines with excitation temperatures that trace the disks' surfaces from ~ 1-100 AU. We use two-dimensional, axisymmetric radiative transfer modeling to retrieve the disks' dust structures and the RADLite raytracer to render model spectra for each disk. A simple step function is used to define the abundance structure and the model spectra are fit to the observed water lines. Fresh results will be discussed, including the inner disk chemical content, snow line radius and fractional water vapor abundances for the young, solar analog RNO 90.

Author: NANCY CHABOT

Volatiles

ORAL

Inner Solar System Volatiles: Insights from Images of Mercury's Polar Deposits

Earth-based radar astronomers first discovered evidence for water ice near Mercury's poles, and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission has acquired additional evidence. These include maps of areas of permanent shadow, active measurements of high and low surface reflectance, thermal modeling consistent with the long-term retention of water ice, and the detection of hydrogen-rich material. More recently, using light scattered from illuminated crater walls, MESSENGER's Mercury Dual Imaging System (MDIS) captured images of permanently shadowed and likely ice-bearing crater floors. These images reveal extensive, spatially continuous regions with distinctive reflectance properties. Within Prokofiev crater, a location where surface water ice is thermally stable, both the sunlit and permanently shadowed areas exhibit a similar cratered texture, but the shadowed area has a uniformly higher reflectance, suggesting the emplacement of water ice on the surface after the formation of even small craters on Prokofiev's floor. In areas where water ice is stable only in the near surface, and where a surficial layer of organic-rich volatile material has been predicted, the images reveal regions with uniformly lower reflectance that extend to the edges of the shadowed areas and terminate with sharp boundaries. The sharp boundaries indicate that the volatile deposits at Mercury's poles are geologically young, relative to the timescale for lateral impact mixing. The images of the polar deposits on Mercury contrast with images acquired by a similar approach for shadowed craters on the Moon. Though laser reflectance measurements have yielded higher reflectance values for Shackleton crater at the lunar south pole, indicative of modest amounts of water frost or a reduction in the effectiveness of space weathering, imaging of permanently shadowed lunar craters has not revealed surfaces with anomalously high- or low-reflectance similar to those found on Mercury. Understanding the different volatile inventories in the polar regions of Mercury and the Moon would provide insights into the nature and delivery of volatiles in the inner Solar System. One possibility for the contrasting observations is that Mercury's polar deposits were recently delivered to the planet by one or several large events. Such a scenario would suggest that the Moon also may have hosted more extensive polar deposits in its past, but that most of the lunar deposits have subsequently been lost or sequestered beneath the surface. Alternatively, the fresh appearance of Mercury's polar deposits may suggest an ongoing process that is able to restore the deposits even at present. The total amount of ice currently at Mercury's poles is substantial, with estimates of ~10^16-10^18g, the high end of which is comparable to the volume of Lake Ontario. If delivered by a single comet, the estimated comet diameter is ~8-40 km. If Mercury's current polar volatile inventory is the product of the most recent portion of a longer process, then a considerable mass of volatiles may have been delivered to the inner Solar System throughout its history.

Author: DAVID GLENAR

ORAL

Volatiles

Influence of Faint Light Sources on the Moon's Permanently Shadowed Regions

Light from numerous sources is incident on the surface within permanently shadowed regions (PSRs) near the lunar poles that are never directly exposed to sunlight. In this study we collate predictions for faint light sources that cover a broad range of wavelengths from the infrared to the far-UV, and consider their potential importance for the conditions within PSRs, which could have implications for the stability of volatiles and the suitability of the Moon as a platform for astronomical observatories. We consider the sources of incident light within a typical near-polar PSR from: (i) direct and scattered Earthshine, (ii) zodiacal light created by sunlight scattered from dust in the inner solar system; (ii) Lyman-alpha resonantly scattered by interplanetary hydrogen; (iii) the diffuse broadband galactic background; (iv) bright stellar sources; (v) emission lines from exospheric species that vary in intensity depending on the space environment at the Moon, which are typically dominated by sodium and potassium; and (vi) sunlight scattered by exospheric dust. For the latter, we consider dust in the lunar exosphere created by several processes, including possible naturally occurring transport phenomena, as well as dust agitated by exploration and in-situ resource utilization (ISRU) activities.

Author: JAMES HEAD, III

Volatiles

ORAL

Lunar Regional Pyroclastic Deposits: Evidence for Eruption from Dikes Emplaced into the Near-Surface Crust

Lunar pyroclastic deposits have several modes of occurrence; smaller, more isolated deposits suggest several modes of emplacement related to dike and sill emplacement, including strombolian, hawaiian, and vulcanian activity. The mode of emplacement of largest pyroclastic deposits (>1000 km2) has been less clear; for the Aristarchus Plateau deposits, very high effusion rate eruptions leading to sinuous rilles and associated pyroclastic emplacement have been implicated. A candidate modes of emplacement comes from analysis of the Orientale dark ring, a 154km diameter pyroclastic deposit that emanates from a linear depression interpreted to be a remnant elongated vent at the top of a dike; a wide dike stalled just below the surface, and the low-pressure environment led to gas buildup along the dike top, leading to eruption of an Io-like pyroclastic plume to produce the dark pyroclastic ring. Analysis of ascent and eruption of magma shows that the low-pressure environment associated with dike tip propagation could enhance formation of volatiles during dike ascent so that the dike arrives at the surface with the dike top already saturated with magmatic foam, and not requiring secondary buildup. Could this mechanism, arrival of volatile magmatic foam-laden dikes to the shallow subsurface, perhaps combined with further shallow crustal gas formation subsequent to stalling, lead to penetration of foams to the surface and eruption of magmatic foams to produce regional pyroclastic deposits? In these cases, the low pressure always present in the propagating dike tip means that as dikes approach the surface their upper tips will consist of a cavity containing gas underlain by a region where gas bubbles concentrate into a foam. If the dike fails to break through to the surface, gas bubbles migrate up through the foam to increase the size of, and pressure in, the gas cavity. Additional foam is generated beneath the gas cavity if the dike is wide enough to allow convection to occur because this brings magma from depth to shallow enough levels for additional pressure-dependent gas release. The Orientale example showed that these processes acting in a ~500m-wide dike produced an ~25-fold gas concentration leading to an explosive eruption emplacing a ~150km diameter circular pyroclastic deposit. A generic example of this process would involve a 100 km long linear rille graben induced by a 300 m-wide dike; magmatic foam would occupy the upper ~ 8 km of the dike where the pressure was less than 40MPa. If the foam evolved the gas would ultimately represent ~5 mass % or ~50000ppm. Foam release would produce an eruption speed of 487 m s-1 ejecting pyroclasts to ~147km. If this magma were deposited as pyroclasts over an area of 100 km (the rille length) x ~ 147km (the maximum range) with a bulk density on landing of 2000kg m-3, the resulting deposit thickness would be ~5m. We infer that essentially all of the observed dark mantle regional pyroclastic deposits on the Moon can be explained by minor variations on this scenario.

SSERVI-ESF14-220

Author: AMANDA HENDRIX

ORAL

Volatiles

REGIONAL VARIATIONS IN FUV LUNAR SIGNATURES

The Lunar Reconnaissance Orbiter (LRO) is currently in orbit at the Moon. The Lyman Alpha Mapping Project (LAMP) onboard LRO has been making measurements of the lunar nightside, dayside and atmosphere since September 2009. We report here on recent work analyzing LAMP dayside data, focusing on weathering and hydration effects in mature vs. immature terrains, including swirls. The LAMP instrument [1] is a photon-counting imaging spectrograph. The entire passband is 57–196 nm, in the far-UV (FUV) spectral region. For dayside measurements, the instrument is operated in “pinhole” mode, with the aperture reduced by a factor of 736. The instrument was usually nadir-pointed in LRO’s characteristic 50-km lunar orbit of the prime mission and provided ~500 m resolution. Approximately once per month LRO flies over any particular region; and although LAMP halts acquistion of dayside data when at high phase angles, there are numerous sets of spectra of each region at differing geometries; the emission angle is small while the incidence angle is larger and varies depending on the beta angle of the orbit. To determine the lunar FUV reflectance, we divide the LAMP data from each latitude bin by the full-disk solar spectrum from SORCE SOLSTICE [2], taken for the day of each observation and convolved to agree with the LAMP resolution and line spread function. The FUV hosts a strong H2O absorption edge near 165 nm, allowing LAMP to study hydration on the Moon [3]. Past analyses of LAMP dayside data (e.g. [3]) have shown that the measurement of spectral slopes in the 164-173 nm range is an indicator of hydration, while spectral slopes in the 175-190 nm region are insensitive to hydration but good indicators of weathering and composition.Here we use this spectral slope information to study hydration and weathering effects in swirls regions (Reiner Gamma, Mare Ingenii, Gerasimovich, Descartes highlands) and in immature regions (e.g. after [4]).References: [1] Gladstone, G. R. et al. (2010) SSR, 150, 161-181. [2] McClintock et al. (2000) Proc. SPIE Earth Obs. Syst., 4135, 225–234. [3] Hendrix et al. (2012) JGR, 117, E12001, doi:10.1029/2012JE004252. [4] Lucey, P. G. et al. (2000) JGR, 105, 20377.

Author: CHARLES HIBBITTS

ORAL

Volatiles

Relevance of UV Reflectance Spectroscopy to Inferring the Compositions of the Moon and Asteroids

Reflectance spectroscopy in the vacuum ultraviolet through visible wavelengths is sensitive to the abundance of opaque materials, especially transition metal cations. Reflectance data were collected for nine glass samples, alumina, anorthite, and water frost. The glass samples are compositionally similar to those in the regolith on the Moon and Mercury, with the notable caveat that some of the iron is oxidized. It is known that the oxidation state of iron affects the visible-NIR region of the spectrum and may affect the UV as well [1,2,3]. Total iron in the glasses varies from 0 to ~21% when expressed as total FeO, with the fraction of iron as Fe3+ varying from 0 to almost 80%, but not correlated to total iron abundance. The abundances of other transition elements are small, with TiO2 being the most abundant and varying from 0 to about 1.5%. TiO2 con-tent does not correlate with FeO. About 100 mg of glass samples ground to talc-like consistency (grain sizes <1 _m) was placed in a copper sample holder mounted in a vacuum chamber. Measurements were obtained with a McPherson 302 vacuum monochrometer with a deuterium source and a PMT detector mounted in front of a MgF2 window coated with a scintillation material. Each sample was maintained at room temperature and ~10-7–10-8 torr. Each sample was heated to ~ 80C overnight at this pressure to remove all adsorbed molecular water. Thus, only hydroxyl, either internal or chemisorbed, remained present. The water ice spectrum is consistent with literature values for fine-grained frost [e.g. 4]. Both water ice and alumna are similar, staying bright into the VUV where single strong absorption feature occurs at ~200 nm for alumina and ~160 nm for water frost. Silicates behave differently due to the presence of cation and transition elements in their compositions (1,2). Both iron abundance and valence state control the position of the absorption near 300 nm, and are responsible for the NUV slope that has been often reported for these materials (3). As iron concentration decreases, the NUV drop off near 400 nm shifts to shorter wavelengths and the center of the absorption band also shifts shortward. The effects of iron oxidation in the VUV are small compared to the effects of iron abundance. The position of the absorption band near 300 nm and the brightness of the VUV continuum near 225 nm are both sensitive to changes of a percent or less in iron abundance and may provide a an additional means for quantifying the iron abundance of low iron minerals and glasses. Acknowledgement: This work has been supported by NASA grants: NLSI NNA09DB31A, SSERVI NNA14AB02A, PGG NNX10AI58 and LASER NNX11AO54G.References: [1] Sigel, G.H., (1974), J. Non-crystalline Solids, 13, 372-398. [2] Tippins, H.H., (1970), Phys. Rev. B, 1,1, 126-135. [3 Pieters, C.M & Englert, P.A., (1993), Univ. Cambridge Press. [4] Hendrix, A.R. and C.J. Hansen, (2008), Icarus, 193, 323-333

Author: SHUAI LI
ORAL

Volatiles

Quantitative mapping of hydration in lunar pyroclastic deposits and implications for lunar volcanic processes

Lunar pyroclastic deposits represent early volcanic processes on the Moon capable of informing us of volatiles and eruption processes. Mapping of lunar surface hydration (H2O/OH) using M3 spectral reflectance data, corrected for thermal emission effects, shows that pyroclastic deposits exhibit much higher hydration levels than surrounding terrains. We have examined eleven large pyroclastic deposits (> 1000 km2) between 30° N and 30° S to assess detailed variations in hydration level and possible links to morphology and eruptive processes. These eleven deposits can be classified into three groups based on their average hydration levels. Pyroclastic deposits at Aristarchus, Sulpicius Gallus, and Humorum exhibit areally extensive high abundances of hydration (e.g., < 500 ppm on average), whereas Rima Bode, Montes Harbinger, and Moscoviense exhibit moderately high abundances of hydration (< 200 ppm on average). Taurus Littrow, Montes Carpatus, Vaporum and Nectaris have lower hydration levels (< 100 ppm on average) and Aestuum is an outlier, showing no detectable hydration absorptions in M3 data. Locations with the highest hydration levels correspond to dark, smooth regions in LROC WAC and earth-based S band RADAR CPR data, consistent with previous observations of lunar pyroclastics. In addition, average hydration content in the pyroclastics is linearly correlated with the spatial extent (area) of each deposit. If the hydration signature in these deposits represents volatiles (water) from the lunar interior, as opposed to solar wind implantation, then these detections provide important information on the volatile content of magma sources and constraints on degassing during eruption events. The different levels of hydration that we observe might indicate heterogeneity in volatile content of magma sources, different cooling rates, or different degrees of degassing. The lack of detectable hydration at Aestuum may be due to water-poor magmas or significant loss of volatiles during eruption and emplacement, and this deposit is known to be associated with distinct (spinel-bearing) mineralogies. The LROC NAC images at these large pyroclastic deposits show that the hydration abundances might be controlled by the thickness of glass-rich layers and/or the purity of the volcanic glass in the deposits. To understand the linear trend between the pyroclastic hydration level and areal extent we will also estimate the thickness of each pyroclastic deposit to provide an estimate on the volume of pyroclastic material. These volume estimates can be used as inputs for volcanic eruption models to calculate the required volatile content (H2O) to account for the observed size of each deposit, which in turn can be compared to our observed hydration levels from M3 data. Pyroclastic hydration can also be complicated by loss via diffusion after deposition, thus we also explore a post-emplacement diffusion model for lunar pyroclastics to understand the retention potential of water in volcanic glass at the lunar surface over geologic timescales.

Author: TIMOTHY LIVENGOOD
POSTER

Volatiles

Neutron Remote-Sensing at the Moon: Modeling the Empirical Variation with Altitude of Neutron Flux for the Lunar Exploration Neutron Detector (LEND)

The Lunar Exploration Neutron Detector (LEND) instrument on the Lunar Reconnaissance Orbiter (LRO) employs a collimator to improve the spatial resolution for neutron remote-sensing of hydrogen-rich volatile deposits on the Moon, with the primary goal of mapping deposits of water at the Moon's cold high latitudes. The collimator reduces the flux of lunar neutrons reaching the detector element from off-nadir directions so that neutrons reaching the detector through the narrow acceptance angle of the collimator opening contribute the primary signal. Verifying the component of epithermal neutrons that is detected in collimation is essential to estimating the actual concen-tration of water stored in localized deposits.

Author: TIMOTHY LIVENGOOD

ORAL

Volatiles

Evidence for Diurnally Varying Hydration at the Moon's Equator from the Lunar Exploration Neutron Detector (LEND)

We detect hydrogen-bearing volatiles, most likely water and hydroxyl, concentrated near the Moon's dawn terminator by an active daily cycle of surface hydration and dehydration. This represents a potential volatile resource for in situ resource utilization (ISRU) that is distilled by natural processes and thus may be accessible at minimal energy cost. Measurements by the Lunar Exploration Neutron Detector (LEND) on the polar-orbiting Lunar Reconnaissance Orbiter (LRO) spacecraft detect hydrogen in the regolith through the localized suppression of epithermal neutron flux from the Moon's surface. At low latitude, the greatest flux suppression is found at dawn, with the least suppression and least hydrogenation in the lunar afternoon. This non-uniform and asymmetric distribution can persist only if a population of hydrogen-bearing volatiles is mobile across the sunlit lunar sur-face in the morning sector with an average horizontal velocity of 4.3 m/s in the anti-sunward direction, enabling the detected hydrogen to remain fixed with respect to the Sun while the Moon rotates.

Author: RICHARD MILLER

ORAL

Volatiles

New Insights Into the Polar Depth Distribution of Hydrogen at the Lunar Poles

We report new results on the depth distribution of enhanced hydrogen abundances at the Moon's North and South polar regions. The spatial distributions of hydrogen burial depth at both lunar poles have been estimated using a recent reanalysis of the epithermal and fast neutron datasets from NASA's Lunar Prospector mission, proven likelihood-based statistical analysis techniques, and comprehensive Monte Carlo simulations. Polar burial distributions provide additional insight into the processes relevant for lunar volatile deposits including burial, migration/mobility, and potentially their origin. Additional work includes comparisons with insolation, topographical, and temperature spatial distributions.

Author: WES PATTERSON
ORAL

Volatiles

Mini-RF Bistatic Observations of Cabeus Crater

The Mini-RF instrument aboard NASA's Lunar Reconnaissance Orbiter (LRO) is currently acquiring bistatic radar data of the lunar surface in an effort to understand the scattering properties of lunar terrains as a function of bistatic (phase) angle. Previous work, at optical wavelengths, has demonstrated that the material properties of lunar regolith can be sensitive to variations in phase angle. This sensitivity gives rise to the lunar opposition effect and likely involves contributions from shadow hiding at low phase angles and coherent backscatter near zero phase. Mini-RF bistatic data of lunar materials indicate that such behavior can also be observed for lunar materials at the wavelength scale of an S-band radar (12.6 cm). Radar observations of planetary surfaces provide important information on the structure (i.e., roughness) and dielectric properties of surface and buried materials. These data can be acquired using a monostatic architecture, where a single antenna serves as the signal transmitter and receiver, or they can be acquired using a bistatic architecture, where a signal is transmitted from one location and received at another. The former provides information on the scattering properties of a target surface at zero phase. The latter provides the same information but over a variety of phase angles. NASA's Mini-RF instrument on LRO and the Arecibo Observatory in Puerto Rico are currently operating in a bistatic architecture. This architecture maintains the hybrid dual-polarimetric nature of the Mini-RF instrument and, therefore, allows for the calculation of the Stokes parameters that characterize the backscattered signal.Circular Polarization Ratio (CPR) information is commonly used in analyses of planetary radar data, and is a representation of surface roughness at the wavelength scale of the radar (i.e., surfaces that are smoother at the wavelength scale will have lower CPR values and surfaces that are rougher will have higher CPR values). High CPR values can also serve as an indicator of the presence of water ice.Bistatic data for the south polar crater Cabeus has been acquired on four occasions and these data cover a phase angle range of 0° to 18°. When viewed at near zero phase, the floor of Cabeus crater shows an enhancement in CPR with respect to surrounding materials. This is not apparent in data acquired of Cabeus crater when Mini-RF operated in a monostatic mode. Further, when viewed at phase angles of several degrees, the floor of Cabeus crater shows a suppression of CPR with respect to surrounding materials. This scattering behavior for the floor of Cabeus crater indicates a clear opposition effect at low phase angles that is consistent with the presence of water ice. We suspect that the difference in the scattering behavior observed with a monostatic architecture is related to the grazing incidence (~85°) at which the region is viewed by Mini-RF when operating in a bistatic mode. This would suggest that the water ice observed would need to be confined to a relatively thin layer, near the surface.

SSERVI-ESF14-227

Author: ANDREW RIVKIN

POSTER

Volatiles

Spectral Characterization and Mathematical Removal of Adsorbed Water

Water and OH have strong absorptions in the 3-μm spectral region. However, the exact band centers shift with type of water/OH (adsorbed vs. structural, for instance) and with host material. The details of these relationships are poorly-known, primarily due to a dearth of measurements under appropriate conditions.Much of the motivation for these measurements have come from spacecraft observations in which OH/H2O absorption features in reflectance spectra of airless bodies have been unexpectedly found in surfaces previously thought to be 'dry' However, most asteroidal data in the 3-μm region has been obtained by ground-based telescopes, and because of very low transmission through the Earth's atmosphere, the 2.5-2.85 μm spectral region is typically omitted from published spectra, often confounding the detection of water/OH bands. While the carbonaceous chondrite and their parent asteroids have broad enough absorptions to be detected at wavelengths greater than the atmospheric "water gap" the detection of small amounts of OH like what we see on the Vesta and may see on non-carbonaceous NEAs is much more dependent upon proper modeling and calibration without the 2.5-2.85 μm region.Most laboratory spectra available for meteorites and planetary materials have been obtained under ambient atmospheric conditions. While they are well-suited for the 0.3-2.5 μm region where work on silicate compositions is done, they are plagued by adsorbed terrestrial water and show deep bands in the 3-μm region. With data from the Rosetta flyby of Lutetia available in the PDS (and anticipating future data from Dawn and the Japanese AKARI spacecraft), understanding the spectral behavior of planetary materials, including nominally anhydrous minerals that may have small amounts of water/OH affecting this wavelength region will be critical to our compositional interpretations. As part of the VORTICES team, we are pursuing a set of laboratory experiments and spectral modeling tasks to measure "truly" anhydrous materials and quantify the spectral shapes of adsorbed water in varying conditions, with the ultimate goals of mathematically removing the signature of adsorbed water from the wealth of available RELAB data and greatly expanding the number of endmembers available for mixture modeling of asteroidal and planetary surfaces. We will discuss our plans for this project and share our progress to date.

SSERVI-ESF14-228

Author: KATHARINE ROBINSON

ORAL

Volatiles

Varied H concentration and isotopic composition in the Lunar Interior

Water from the lunar interior has been measured in olivine-hosted melt inclusions, ferroan anorthosite plagioclase, residual glass in a KREEP basalt, and apatite grains from all other major lunar rock types (mare basalts, alkali suite, Mg-suite).The common goal of these measurements is two-fold: to constrain the water content of the bulk Moon, and to determine the source(s) of the Moon's water via hydrogen isotopic ratios. Estimating the pre-eruptive water content of the parental magma from glasses and melt inclusions is fairly straightforward, and it was initially thought that similar estimates could be made using OH abundances in apatite. It has recently been shown that volatile partitioning into apatite is more complex than previously thought, invalidating estimates of parental melt water content from apatite. However, apatite data is still a useful recorder of D/H ratios and relative water contents might be discernible among different rock types. Analysis of the picritic glass beads and melt inclusions showed that they originated from a magma with ~1000 ppm H2O. The source region for that magma would have contained 100 ppm, assuming ~10% partial melting to form the pyroclastic magmas. In contrast, our measurements of residual quenched glass in KREEP basalt fragments in 15358 contain 58-95 ppm H2O. Based on the modal abundances of the glass and accounting for H loss, the initial melt would have contained ~100 ppm H2O. The KREEP source would have thus contained ~10 ppm, an order of magnitude less than the picritic magmas. These calculations are somewhat rough, but indicate that there are at least two possible water reservoirs in the lunar interior.Water data from lunar apatite also indicates multiple reservoirs in the lunar interior. Water content of apatite in the major rock suites varies by 10-50x and seems to be related to rock type. KREEP-rich samples have the driest apatite, while mare basalt apatite is more water-rich. Additionally, the delta-D values of apatite vary widely. Elevated delta-D in mare basalts are almost certainly caused by H loss from lava flows, but some evolved, intrusive rocks also appear enriched in D (+200 to +500 permil). However, there are some samples that fall in the range of the terrestrial upper mantle (-140 to +60 permil D). Our measurements of apatite in quartz monzogabbro 15404, 55 have the lowest delta-D (-500) values reported from the Moon so far, indicating a third, low D source inside the Moon (Robinson et al. 2014 LPSC).Varied water concentrations and delta-D in the lunar interior probably reflect a combination of processes involved in lunar formation, primary differentiation in the magma ocean, secondary magmatism, and addition of material to the Moon after accretion. Which process(es) dominated is far from clear. The first step in increasing our understanding of water distribution in the Moon is to pin down its variability in all rock types and relate that to other important parameters, such as the abundances of highly volatile elements.

SSERVI-ESF14-229

Author: MATTHEW SIEGLER

ORAL

Volatiles

Evolution of Lunar ice stability

The polar regions of the Moon and Mercury have similar permanently shadowed environments, potentially capable of harboring ice. However, this has not always been the case for the Moon. Roughly 3±1 Gya, when the Moon is believed to have resided at approximately half of its current semimajor axis, lunar obliquities have been calculated to have reached as high as 77o (Goldreich et al. 1969; Ward, 1975; Wisdom and Touma, 1994; Siegler et al., 2011) This is due to a dissipation driven spin orbit coupling known as a Cassini State. Combined with the modeled orbital inclination for this time period, this left the lunar poles with a maximum solar illumination angle (here termed solar declination) of approximately 83o (Siegler et al. 2011). Lunar polar cold traps did not exist. Since that era lunar obliquity has secularly decreased, creating environments over approximately the last 1-1.5 Gyr (assuming near current recession rates) where water ice, if delivered to the Moon, should be stable. In analogy to Mercury, where evidence points to nearly pure ice deposits likely deposited by a large cometary impact within the last several 10's of Mys (Crider and Killen, 2005), we would expect similar thermal environments on the evolving Moon to also retain relatively pure water ice for 10's to 100's of Mys. Though evidence points to a lack of Mercury-like pure ice deposits on the Moon (Campbell et al, 2006; More refs), this analogy makes it difficult to explain how all ice from of any similar impact over the past 1.5 Gyr could be lost. Essentially, to explain the paucity of ice in locations where it would be stable in the current thermal environment, one must claim that no comet similar to the one(s) which struck Mercury (assumed in the past few 10's on Myr) has struck the Moon in several hundred Myrs or longer. One hypothesis to explain this discrepancy might be that such a cometary impact occurred not in today's lunar thermal environment, but a past one. If ice were delivered during a past epoch, the distribution of ground ice would be dictated not by present day temperatures, but rather by these ancient temperatures. This ancient ice, buried and mixed into the regolith by impact gardening. In this paper, we attempt to recreate the thermal environments for past lunar orbital configurations to characterize the history of lunar environments capable of harboring ice. We will develop models of ice mobility and degradation to examine likely fossil remains of past ice delivery (e.g. a comet impact) that could be observed on the present moon. We then compare this to interpreted geographical distribution of lunar ground ice from existing data sets.

Author: DOUGLAS STANDART

POSTER

Volatiles

Magmatic Lunar Hydroxly and Water: Redefining the KREEP Terrane Boundary

Early in the evolution of the Moon, towards the late stages of differentiation of the early lunar magma ocean, a relatively thin layer of melt would have remained and been enriched with thorium, water, hydroxyl, and other incompatible materials as a result of fractional crystallization of the lunar crust and mantle. This layer is known as KREEP (potassium, rare earth elements, phosphorus). Lunar crust that shows high concentrations of thorium and hydroxyl/water may indicate interaction with the KREEP layer. Using results from the Lunar Prospector Gamma Ray Spectrometer (LP-GRS), we selected thorium anomalies on the Moon in an effort to detect KREEP-rich or material using hyperspectral imagery. Four sites were chosen: Lassell Crater (15 S, 8 W), Hansteen Alpha (15 S, 50 W), Gruithuisen Domes (36 N, 40 W), and the Compton-Belkovich Thorium Anomaly (61 N, 100 E). Three of these sites are non-mare volcanic features within the Procellarum KREEP Terrane (PKT), the area on the lunar nearside which has a KREEP signature, while Compton-Belkovich is located on the lunar farside. The Moon Mineralogy Mapper (M3) hyperspectral imager was used to analyze the composition of these locations. The reflectance spectra gathered from these sites all show pronounced absorptions at ~2.8 microns, indicating the presence of hydroxyl/water. Maps of the 2.8-micron absorption show concentric patterns centered on these sites with the deepest absorptions at their centers. Digital elevation models and high-resolution imagery from the Lunar Reconnaissance Orbiter-Near Angle Camera (LRO-NAC) show that many of the 2.8-micron absorption maxima are associated with morphologies consistent with volcanic domes or vents. This association suggests that the volcanic features are associated with potential sources of magmatic volatiles and were the sites degassing those volatiles. In order to measure the concentration of hydroxyl/water associated with the 2.8-micron absorptions, we measure the area of a Gaussian curve fit to the absorption spectra. The area of the Gaussian curve, an assumed particle size of 45 microns, the density (3.0 g cm-3), and an integrated molar absorption coefficient are parameters used to determine the concentration of hydroxyl/water creating the absorption. To ensure that these absorption features are the result of KREEP-related water that is intrinsic to the Moon, and are not associated with solar wind implanted water, we compare available M3 images from different optical periods in the lunar day. Whereas the concentration of implanted water should vary on a diurnal basis as it migrates through the lunar regolith and exosphere, the nearside volcanic features show consistent 2.8-micron absorptions throughout the lunar day, a behavior consistent with intrinsic water. A magmatic water source would support the hypothesis that the lunar interior is more hydrous than previously thought; and it suggests that KREEP may underlie the far side highlands near CBTA and possibly other areas outside PKT.

SSERVI-ESF14-231

Author: MICHAEL ZIMMERMAN

ORAL

Volatiles

Simulations of the thermal and plasma environment within lunar pits and lava tubes: could cryogenic regions trap ions from the solar wind?

Observed lunar holes and hypothesized lava tubes have been identified as possible targets for human exploration because they provide at least partial shelter from solar wind, radiation, and extreme heat variations. In this work we begin to characterize the full thermal cycle and plasma particle flow within an idealized lunar pit including a subsurface lava tube. Finite-difference heat transport simulations show development of a quasi-steady lunar heating cycle over thousands of lunar days, and plasma treecode simulations are used to model daily surface charging, photoemission, and ion flow into the pit. Interestingly, preliminary simulations of a 50 m-wide and 50 m-deep pit show that ions flow directly onto the hot, illuminated regions of the pit at times around local noon when the solar wind flow and solar radiation are close to vertical. The solar wind could thus provide a daily source of hydrogen and other ions that is quickly sublimated, with some fraction hopping laterally into adjacent lava tubes where it could remain cryogenically trapped.